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Phenology, herbivory, and bioeconomics of the bean leaf beetle on soybean

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Phenology, herbivory, and bioeconomics of the
bean leaf beetle on soybean

by

Richard Brian Smelser

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INTRODUCTION

Integrated pest management was developed to replace the prevailing pest control strategy of indiscriminate use of agricultural chemicals that was initiated during the post-World War II era. The extensive use of pesticides in agriculture had caused several economic and environmental problems. Unnecessarily high levels of insecticide pressure had encouraged the development of resistance by several pest species. Also, beneficial species had been sufficiently reduced to allow a resurgence of target pests. In some areas, the number of pesticide applications per season in certain crops increased tremendously to counteract this phenomenon. Increasing concentrations of pesticides in the environment caused disruption of neighboring ecosystems through biomaginification of toxins (clorinated hydrocarbons) into higher trophic levels. Also, runoff from fields into streams and lakes drastically reduced aquatic populations. Pesticides even made their way into the ground water, threatening the safety of drinking water for farm families and rural communities.

A major objective, therefore, of integrated pest management became the reduction of pesticide use. It was understood, however, that alternate strategies must be economically sound to encourage their use in the agricultural community. The economic-injury level concept was initiated to help solve this problem, and it has become the cornerstone of integrated pest management practice. The principle of this strategy is to determine the insect densities required to justify the use of a management tactic, (i.e., to establish cost/benefit guidelines). In other words, when did the benefit of applying a pesticide equal the cost of its application.

A need has arisen within the 1980s for the development of improved management guidelines for the bean leaf beetle on soybean. This insect has been a common resident of soybean fields but only recently has developed into one of the most important pests of this crop in the Midwest. Previously, the species was known primarily for its leaf feeding behavior. During the early 1980s, however, attention was shifted to bean leaf beetle pod feeding activity, with reports of this late-season damage increasing through the decade. Adults are responsible for injury to pods, and they do so by removing the outer green tissue of the pod. This leaves sections of pod surface in which only a thin layer covers the seed. Such injury encourages increased weathering of seeds and allows secondary pathogens to enter. Many growers have experienced economic penalties when marketing their crop because of considerable seed-quality reduction. Some producers and pest managers have been concerned that additional loss may be caused by pod clipping, when the bean leaf beetle feeds near the base of soybean pods.

Management guidelines for late-season bean leaf beetle adult injury in the Midwest are based on nominal economic thresholds. These values have been determined by the experience of pest managers in the field and, therefore, are not based on sound experimental data. Information concerning the relationship between insect density, feeding, and the injury inflicted, as well as, a quantification of the effect of this injury on crop utility are essential elements for proper management guidelines. A portion of this dissertation research was directed toward producing economic-injury levels and determining management guidelines for the bean leaf beetle on soybean during late season.

Although the economic-injury level forms a basis for IPM practice, it has limited application without other information. Pest management guidelines can be developed only if an understanding of the biology of the pest and its host are available. Information such as life cycles and phenologies of both organisms must be ascertained.

Considerable research on the biology of the bean leaf beetle has been documented. In the Midwest phenological studies were conducted in Minnesota and Illinois. Information from these projects indicated that bean leaf beetle populations produce one generation per year in Minnesota and two generations per year in Illinois. The phenology of populations in Iowa, however, has not been ascertained. A sampling study was initiated in Iowa to determine if populations in this state resemble the phenology of populations in Illinois or those in Minnesota. A segment of this dissertation discusses the results of this research.

Pursuant to the foregoing, the objectives of this study were the following:

1) Determine the phenology of bean leaf beetle adults on soybean and alfalfa in Iowa.
2) Ascertain seasonal and diurnal distribution of sex ratio, female reproductive status, and relative proportions of adult color forms.
3) Quantify the relationship between bean leaf beetle adult density and injury on soybean stem, leaf, and pod components during late season.
4) Assess the effect of bean leaf beetle adult feeding on soybean seed yield and seed quality.
5) Formulate economic-injury level equations for late-season injury on soybean by bean leaf beetle adults.

6) Determine the dispersion patterns of bean leaf beetle adults and injured pods.

7) Develop sequential sampling plans for late-season management guidelines.

LITERATURE REVIEW

The majority of the studies on the bean leaf beetle have been conducted in North Carolina, Illinois, Minnesota, Arkansas, and Louisiana. These studies cover various aspects of the biology, ecology, and bioeconomics of this pest. The following discussion contains a summary of the results documented in the literature and is divided into the following sections: 1) history and geographical range; 2) life cycle; 3) host range and injury to plants; 4) seasonal phenology; 5) adult dispersal; 6) natural enemies; 7) phenological relationship with soybean; and 8) pest management guidelines.

History and Geographical Range

Eddy and Nettles (1930) provide a summary of the history of the bean leaf beetle. This insect was first described as *Cerotoma trifurcata* by Forster in 1771 (Chittenden 1897). The only other description was made by Fabricus in 1801 (*C. caminea*). Popenoe (1877) was the first to report the bean leaf beetle as a pest and in 1889 gave it the common name that is used to this day. In Kansas during 1875 he observed the adults feeding on "dwarf beans" (probably *Phaseolus sp.*). The insect was later observed attacking beans and cowpeas in Louisiana and Indiana during 1887 (Webster 1888). Chittenden (1897) also gave reports of the adult found on string beans in New Jersey and on lima and wax beans in Delaware. He states that the bean leaf beetle had been observed from the plains to the east coast and from southern Canada to the Gulf States.

Life Cycle

The bean leaf beetle undergoes complete metamorphosis, with its life cycle including egg, three larval stages, prepupa (end of third instar), pupa, and adult. The egg is about 0.8-mm long and spindle shaped. Its color is dull yellow to orange (depending on age), and its surface is coarsely reticulated. Eggs are laid in the soil near the base of the host stem, with most eggs placed within 2.5 cm of the tap root (Levinson et al. 1979). Bean leaf beetle larvae are white with a black head capsule and anal shield and may be easily confused with corn rootworm larvae (*Diabrotica* sp.). They generally grow to a length of 10mm and feed on roots, root hairs, and root nodules (Deitz et al. 1976). First and second instars do not move outside of the range of their hatching sites. Third instars, however, disperse away from the tap root but remain within 23 cm of the crop row (Levinson et al. 1979). Near the end of the third stadium, the larva will construct an earthen cell and enter a resting stage. During this stage, the insect will not feed and undergoes physiological preparation for metamorphosis into the pupal stage. Adults emerge from the pupal cell and leave the soil to feed on above portions of the plant. They range in size from 3.5 to 5.0 mm and have an oval-shaped body. Their elytra vary from pale yellow to red and are commonly marked with three pairs of black spots. Some beetles have a reduced number of spots and others have none. All adults, however, have a black triangle at the base of their elytra. Sex of adults is easily determined by inspection of the face. A large portion of the male face is yellow, but all of the female face is black (Horn 1893; Deitz et al. 1976; Isely 1930; Eddy and Nettles 1930).

Host Range and Injury to Plants

Both larvae and adults of the bean leaf beetle feed on various cultivated legumes, including soybean, cowpea, and species and varieties of *Phaseolus* (Chittenden 1897; Eddy and Nettles 1930; Isely 1930). Adults have been observed feeding on several wild plants when a supply of their cultivated hosts is not available. Until the 1980s it was believed that they fed only on members of the Leguminosae - probably including alfalfa, *Medicago sativa* L. and red clover, *Trifolium pratense* L.. Recently, adults have been found feeding on non-leguminous hosts, including *Urtica dioica* L. (stinging nettle); *Laportea canadensis* (L.) Gaud. (Urticaccae) (wood nettle); and *Euonymous atropurpurea* Jacq. (Celastraccae) (Helm et al. 1983).

Both larvae and adults of the bean leaf beetle are capable of inflicting injury to the plant. Larvae feed mostly on root nodules and have been reported to cause considerable stress on cowpea and soybeans. For example, on soybean, reduced number and size of nodules and a decrease in leaf area and yield have been associated with high bean leaf beetle larval densities (Leonard and Turner 1918; Newsom et al. 1978). Most attention has been given to adult plant injury. As its name implies, the bean leaf beetle is known best for leaf feeding. On some hosts, such as soybean, this pest will often feed on pods during late season (Shortt et al. 1982). The bean leaf beetle is also a transmitter of bean pod mottle virus on soybean. This disease is found primarily in southern states, but has recently been observed in Illinois (Walters 1964; Waldbauer and Kogan 1976a).

Seasonal Phenology

The bean leaf beetle overwinters as an adult in a wide range of habitats. It has been found along road sides, ditches, canals, wind-rows, meadows, shrubby areas, and open and dense woodlots. Adults have even been found in litter between soybean rows when the beetles of the last generation of the season developed late (Boiteau et al. 1980b). In Arkansas, more overwintering beetles were found in wooded areas than along field margins, and none was found in fallow fields or grass levies (Mueller and Haddox 1980). Jeffords et al. (1983) reported that most appreciable bean leaf beetle infestations were located near areas of heavier forestation.

Adults leave overwintering quarters during the spring. The beginning of emigration varies by latitude. In North Carolina and Illinois, beetles start to leave overwintering areas during mid-April (Boiteau et al. 1979b; Jeffords et al. 1983). Spring emigration begins considerably earlier in states to the south. For example, beetles were caught in emergence cages in Louisiana as early as the beginning of March (Payah and Boethel 1985). In northern states, such as Minnesota, adults do not start leaving overwintering areas until mid-May (Loughran and Ragsdale 1986).

The duration of spring emigration also varies geographically. In North Carolina, adults were observed leaving overwintering quarters from mid-April until early July (Boiteau et al. 1979b). Almost all of the overwintering beetles in Illinois, however, leave overwintering sites by the beginning of June (Jeffords et al. 1983). Also, in Minnesota, 90 percent had emigrated between mid-May and 9 June during one year (Loughran and Ragsdale 1986).

In Illinois, Jeffords et al. (1983) discovered that the seasonal occurrence of bean leaf beetle emigration from overwintering was influenced by temperature, with warmer springs causing earlier emigration. They demonstrated that a model based on degree-days provided more reliable estimates of the time of emigration than those estimates determined by a model based on calendar days.

The sex of adults also determines time of emergence. Studies in Minnesota, North Carolina, and Louisiana revealed that males enter and leave overwintering areas before females (Loughran and Ragsdale 1986; Boiteau et al. 1979a; Payah and Boethel 1985).

If a host crop is not present, bean leaf beetles will forage on alternate hosts, such as those mentioned above and wait until a preferred host is available. After the appearance of the preferred host, the adults will immediately colonize the field and become dispersed throughout (Boiteau et al. 1980a).

The number of bean leaf beetle generations in a season also varies by latitude. In Arkansas and South Carolina, three generations per year have been reported (Isely 1930; Eddy and Nettles 1930). Sampling studies to the north of these states, in Illinois and North Carolina, have indicated that two generations occur each year on soybean (Kogan et al. 1974; Boiteau et al. 1980a). Only one generation was observed on soybean in Minnesota (Loughran and Ragsdale 1986).

Boiteau et al. (1979a) have suggested that the bean leaf beetle exhibits a reproductive diapause. This was determined based on their observations that in North Carolina the overwintering female has undeveloped ovaries and appreciable fat content throughout the winter. Within days after emergence reproductive development begins, and many females are ready to oviposit when soybeans emerge. These authors also found that many female adults will enter diapause when conditions for egg laying are still favorable. Studies by Loughran and Ragsdale (1986) support the claim of reproductive diapause.

Adult Dispersal

The two major dispersal periods of the bean leaf beetle occur when 1) the adults leave overwintering areas in the spring to colonize fields, and 2) they leave fields that are approaching harvest and move to overwintering quarters. In North Carolina, F_1 adults also exhibit a dispersal period. Some of these F_1 beetles enter overwintering areas, but others enter late planted fields (Boiteau et al. 1979c). In Louisiana movement to overwintering areas may start as early as mid-July (Payah and Boethel 1985); however, this phenomenon does not begin until mid-August in Minnesota (Loughran and Ragsdale 1986).

Adults are primarily daytime fliers. They will not fly in strong winds or heavy rains. The preference of low winds indicates that the beetles prefer to control their flight path. Flight-height studies in North Carolina indicated that 92 percent of adults fly below 2.5m above the ground. Most flights are short, rarely exceeding 30m. Exceptions to these values occur during periods of migration, such as to and from overwintering areas. During these events some beetles have been collected as high as 50 m, indicating that winds may be utilized for long-range movement (Boiteau et al. 1979c; Boiteau et al. 1980a).

Natural Enemies

The role of natural enemies in the population dynamics of the bean leaf beetle is not well understood. An internal tachinid parasitoid, *Celatoria diabroticae* (Shimer), was reported in Arkansas (Isely 1930), Mississippi (McConnell 1915), South Carolina (Eddy and Nettles 1930), and Louisiana (Herzog 1977). Herzog states that this insect exhibits little control during peak beetle abundance. Another parasitoid, *Hyalomyodes triangulifer* (Loew) (Diptera: Tachinidae), was found at low parasitization rates by Herzog (1977) and Marrone et al. (1983) in Louisiana and North Carolina. In Minnesota Loughran and Ragsdale (1986) discussed parasitization by another Tachinid, *Medina* n. sp., and indicated that several beetles were parasitized in soybean fields adjacent to alfalfa. A pathogen, *Beauveria bassiana* (Balsamo) Vuillemin was found to cause appreciable mortality in overwintering beetles in Louisiana (Payah and Boethel 1986).

Phenological Relationship with Soybean

A critical factor determining the abundance of the bean leaf beetle in soybean is the relationship between the phenologies of the insect and the plant. Boiteau et al. (1980a) sampled several soybean fields that were planted on various dates and observed that beetle dynamics were appreciably effected by differences in planting dates, with late-planted fields escaping heavy injury. In Illinois most early-season problems occurred in areas near "extensive overwintering habitats" and where considerable amount of soybeans were planted before 20 May (Jeffords et al. 1983). Newsom et al. (1975) utilized this information to develop a control strategy. They indicated that a soybean strip could be planted early to attract beetles and then sprayed for control of this pest.

Pest Management Guidelines

No economic-injury levels have been calculated for the bean leaf beetle that are based on experimental determinations of adult injury/yield loss relationships. Kogan (1976), however, used estimated adult feeding rates to calculate economic injury levels for bean leaf beetle defoliation at various soybean stages. Economic injury levels for bean leaf beetle defoliation at various soybean stages were also calculated by Boiteau et al. (1979d). They used defoliation threshold data from Lau (1975) in a model developed for soybean defoliators (Ruesink 1975).

Boiteau et al. (1979d) used Ono's (1967) and Iwao and Kuno's (1971) methods to prepare charts that provide minimum sample sizes for selected precision levels. From these data Boiteau et al. suggested that 30 to 50 20-sweep samples would give estimates of bean leaf beetle densities that are satisfactory for pest management decision making. They also formulated a sequential sampling plan that used their economic-injury level calculations.

SECTION I. PHENOLOGY OF THE BEAN LEAF BEETLE ON SOYBEAN AND ALFALFA IN CENTRAL IOWA

ABSTRACT

Bean leaf beetle, *Cerotoma trifurcata* (Forster), adults were sampled from 1986 through 1988 in soybean and alfalfa in central Iowa to ascertain the seasonal and diurnal phenology of this pest. Data from all three years indicated that two generations of this insect occur in Iowa. Overwintering adults inhabited alfalfa before soybean emergence, colonized soybeans immediately after seedlings appeared, and died by late June. F_1 adults were abundant from late June to mid- or late August, and F_2 adults from early August to soybean maturation. Females were more abundant than males among overwintering and F_1 adults, but neither sex of F_2 adults was more numerous. The yellow/red adult ratio was greater during the fall than in the spring, indicating greater winter survivorship of red adults. For the period from 0830 h to 2030 h, adult abundance was least at 0830 h and 1000 h, the period of heavy dew on the soybean canopy. From 1300 h to 1600 h captures of females with developing ovaries declined, whereas catches of females with fully developed eggs increased.

INTRODUCTION

The bean leaf beetle had been an infrequent pest of soybeans in the Midwest, with most economic losses caused by seedling injury. During the 1980s, however, reports of economic infestations of this pest have been increasing, and pod injury has become preeminent. An understanding of the phenology of this pest is essential in the development of a successful pest-management program. Important applications of this information include improved timing of scouting procedures and proper implementation of management tactics.

The BLB develops three generations a year in Arkansas and South Carolina (Eddy and Nettles 1930, Isely 1930), two generations in North Carolina (Boiteau et al. 1980a), two generations in the central third of Illinois (Kogan et al. 1974, Waldbauer and Kogan 1976b), and one generation in Minnesota (Loughran and Ragsdale 1986). The differences in phenology between Minnesota and Illinois have necessitated seasonal monitoring of the bean leaf beetle in Iowa. Our study concentrated on the adult stage because this is the only stage which feeds on soybean leaves and pods. Also, all other stages develop in the soil and are much more difficult to sample. Sampling was conducted to ascertain adult seasonal phenology and other life-cycle characteristics, including adult abundance, female reproductive status, and sex ratios. A range of color and pattern variations occurs among adults (Kogan et al. 1980). Seasonal abundance of these forms has not been documented for the north-central United States. Our study, therefore, included an analysis of polymorphic ratios.

A final objective was to determine the diurnal abundance of adults in the soybean canopy. This information is important for understanding the effect of sampling time on captures, either for research or pest management purposes. Kogan et al. 1974 conducted the only documented within-canopy, diurnal sampling study for the bean leaf beetle and observed that adult captures were least around noon. They suggested that this was the result of increased egg laying by females and indicated that sex-ratio information would be useful in understanding this phenomenon. Therefore, we evaluated adult abundance, reproductive status, and sex ratio with respect to the time of day.

MATERIALS AND METHODS

Soybean Monitoring

Bean leaf beetle adults were sampled in central Iowa near Manning (1986), Ames (1987 and 1988), and Boone (1988). Two fields were sampled in 1986 (c.v. 'Land O' Lakes L2456' and 'Pella' in one field, and 'Northrup King 1492' in the other field). One field was planted during early May and the other field was planted during late May. The Ames fields (c.v.'Corsoy 79' and 'Preston') were planted early (late April to early May) and within 200 m of alfalfa. The field sampled near Boone (c.v. 'Pioneer 9251') was bordered by corn, oats, and a wooded lot.

In all soybean fields, bean leaf beetle populations were assessed from soybean emergence to stage V4 (Fehr et al. 1971) by direct observation of the plants and the ground along the row (Kogan et al. 1974). Sampling units were 5-m, 10-m, and 15-m lengths of soybean row in 1986, 1987, and 1988, respectively. In 1986, ground cloth sampling (Kogan et al. 1974) was conducted from stage V5 until stage R3 after soybeans had lodged. Fields were sampled with a 38-cm diam. sweep net beginning with stage R3 in 1986 and stage V4 in 1987 and 1988 and ending at harvest. Samples usually were collected every 3 to 4 days from 1100 h to 1300 h in 1986 and from 1400 h to 1600 h in 1987 and 1988. The Boone field sampling was terminated in late July because a miticide application decimated the bean leaf beetle population.

Alfalfa Monitoring

Bean leaf beetle adults were sampled in alfalfa because beetles often leave overwintering habitats before preferred hosts (i.e., soybeans and Phaseolus sp.) are available and inhabit areas where wild or forage legumes are abundant. The importance of alfalfa for bean leaf beetle survival has not been determined (Waldbauer and Kogan 1976b).

Alfalfa fields were sampled in 1987 and 1988 within 200 m of the Ames soybean fields. All fields were sampled by sweep net with eight 40- and 50-sweep units constituting a sample in 1987 and 1988, respectively. Samples were collected beginning at 10 to 15 cm of spring growth and continuing until beetle populations fell to zero in the fall. In 1987, monitoring was terminated in June after beetles disappeared and was reinitiated in August when soybeans in adjacent fields were approaching maturity. The sampling interval was 3 to 4 days and was lengthened after alfalfa cuttings and during periods of zero beetle captures.

Adult Characteristics

Numbers of adults of each sex and numbers of teneral and mature adults (Horn 1893) were recorded each year. Beetles were segregated into two color-form groups, based on the dominance of red or yellow in the elytra. Also, numbers of adults with one pair of conspicuous spots and the numbers of adults with no conspicuous spots were recorded (normal adults have two pairs of conspicuous spots). Females were dissected to determine approximate development status on the basis of the following classification scheme: (1) no egg-size oocytes observed, abdominal cavity filled with fat; (2) some egg-size oocytes colored white or light-yellow present, fat content moderate; (3) some fully developed eggs present, fat content appreciably reduced; (4) fat almost entirely consumed, few or no eggs remaining.

Diurnal Sampling

A sampling series was conducted on 21 July 1988 in a soybean field near Ames. Adults were sampled every 1½ h from 0830 h to 2030 h with three 50-sweep sampling units taken in each of 4 blocks. Soybean rows that were sampled were marked to avoid repeated monitoring of the same areas. Immediately after each sampling run, wind speed (measured with a hand-held anemometer) and atmospheric temperature (measured with a hand-held, aspirated sensor) at 50 cm above the canopy, leaf temperature in the upper canopy (measured with a Telatemp^{R}, model AG42 infrared remote temperature sensor), and 2.5-cm soil temperature were recorded. The numbers of male, female, teneral, and mature beetles were recorded, along with polymorphic form ratios and female development status. Sampling was restricted to daylight hours because this study was designed to provide pest scouting recommendations.

RESULTS

Populations on Soybean

In 1986, two generations of bean leaf beetles were detected in both fields (Fig. 1). Beetles colonized the soybeans within 3 days after seedling emergence (seedlings appeared 15-17 May in field 1 and 31 May in field 2). Many of the first females captured were full of eggs ready to be oviposited (class 3). Overwintering beetles peaked during the last week of May (Field 1) and fell to zero during late June. Increasing adult abundance, along with the first teneral captures, during early July signalled the start of F_1 adult emergence. Three population peaks occurred during the rest of the year. The first two (late July and early August) were seemingly composed of F_1 adults because growing degree-day accumulation between these maximums (253.7 centigrade degree-days) was not sufficient for completion of a generation (366.1 centigrade degree-days from hatching to adult, Turner 1974). Adults in the final peak (mid-September) probably were all members of the F_2 generation. The last class-3 females collected during the season were captured late August, indicating the end of the F_1 generation. All females collected during September had undeveloped ovaries.

In 1987, two generations of BLB were observed. Adults were present on soybeans immediately after seedling emergence (10-11 May). Some females were ready to lay eggs (class 3) within 3 days after soybean emergence. Overwintering-generation adults peaked during late May (Fig. 1). Counts decreased to low levels during mid-to-late June, indicating the end of the

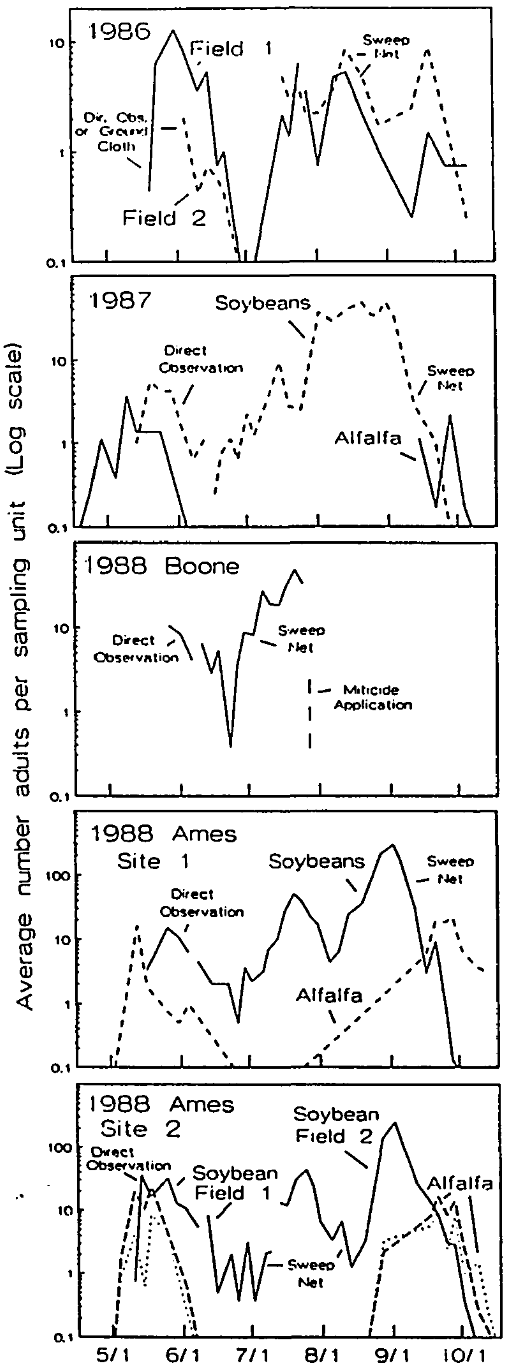


Fig. 1 Seasonal abundance of bean leaf beetle adults in central Iowa.

overwintering generation. The first teneral adults were collected during late June, signalling the start of F_1 adult emergence. A minor peak in abundance that occurred during mid-July was composed entirely of F_1 adults. During late July, a second burst in adult abundance occurred, with populations remaining high until the beginning of September. The large August peak probably was the result of an overlap of a second F_1 peak and a large emergence of F_2 adults. Captures of teneral adults decreased during early August and increased again toward mid-August. The mid-August increase probably was the initiation of the F_2 generation. The last class 2, 3, and 4 females were captured during late August, indicating the end of the F_1 generation. Beetle abundance dropped drastically during early September as the majority of the soybean tissue had matured. Populations remained high through the end of September on patches of younger soybeans.

In 1988, three distinct peaks in the adult population were observed at both of the Ames sample sites, clearly indicating the occurrence of two generations (Fig. 1). Sampling was terminated after 22 July at Boone because the field was sprayed for two-spotted spider mite control. In all fields, overwintering adults were observed on seedlings within 3 days after soybean emergence and were most abundant during mid-to-late May. Some of the first females captured had fully developed eggs. A population decline, along with the last class-4 female occurrence during late June, signalled the end of the overwintering generation. The first F_1 teneral adults were captured during late June. During mid-July, sampling was discontinued at site 1, field 1 and initiated in an adjacent field (field 2, c.v. 'Corsoy 79') because of F_1 beetle migration. The migration occurred possibly because adults were dissatisfied with the quality of the soybean tissue in field 1. In all fields, the F_1 adult population peaked during mid-July and fell during late July and early August. Teneral abundance declined during late July and rapidly increased during early August at site 1 and during mid-August at site 2, indicating the start of F_2 adult emergence. The last class-3 females were collected in mid-August, signalling the end of the F_1 generation. The F_2 adult population peaked during late August and rapidly declined through September. All F_2 females had undeveloped ovaries.

Populations on Alfalfa

The first beetles were detected in alfalfa on 23 April in 1987 and on 4 May in 1988. Populations peaked during early May in 1987 and during mid-May in 1988 and fell during mid-to-late May after emergence of adjacent soybeans (Fig. 1). Beetles disappeared from early June until August. Captures peaked during mid-September, declined rapidly during late September, and fell to zero by early October. No teneral adults were collected in the alfalfa in the spring, and very few were captured during late summer and fall. Seemingly, those tenerals observed emerged in adjacent soybeans and moved to the alfalfa before their cuticle hardened. All classes of females were collected during the spring, whereas only class 1 females were captured during the fall.

Polymorphic Distribution

The proportion of females in the F_2 generation was significantly ($P < 0.05$) less than in the overwintering generation (Table 1). This suggests

Table 1. Mean percent bean leaf beetle adults from each generation in each category (alfalfa and soybean data pooled)

	Generation[a]		
	Overwintering	F1	F2
Males	17.3 b	35.6 a	47.4 a
Females	82.7 a	64.4 b	52.6 b
Yellow	80.8 c	87.9 b	93.3 a
Red	19.2 a	12.1 b	6.7 c
% males that are red	3.0 a	2.8 a	2.8 a
% males that are yellow	97.0 a	97.2 a	97.2 a
% females that are red	22.4 a	17.0 ab	10.4 b
% females that are yellow	77.6 ab	83.0 ab	89.6 a
Two-spots	0.16 a	0.14 a	0.11 a
No-spots	0.13 a	0.21 a	0.38 a

[a]Means followed by the same letter within rows do not differ significantly (P=0.05) as determined by Duncan's multiple range test (Duncan 1955).

that a greater proportion of females than males overwintered successfully. The percentage of yellow adults increased significantly ($P<0.05$) through the season, but this trend was observed only among females. These data indicate that a larger proportion of red adults than of yellow adults seem to survive the winter, and the change in color ratios among generations primarily is determined by female color ratios.

The proportion of adults with one pair of conspicuous spots on the elytra decline during the season. The proportion of adults with no conspicuous spots, however, increased through the season. No significant ($P>0.05$) differences were detected.

Diurnal Study

Significantly ($P < 0.05$) fewer adults (including teneral and mature individuals) were captured at 0830 h and 1000 h than at any other sample times (Fig. 2). Captures peaked at 1130 h, plateaued somewhat during the afternoon, and increased toward evening. No obvious relationship with atmospheric, canopy, or soil temperature was observed. Wind speed seemingly was not a factor in determining adult abundance because it was relatively consistent throughout the day. Dew was present at the 0830 h and 1000 h sample times, and the canopy was dry by 1100 h. This was observed possibly because adults prefer to feed on dry tissue and do not enter the upper soybean canopy until the dew evaporates.

A significant ($P<0.05$) decline of teneral adult captures was detected from 0830 h to 1300 h, and a gradual increase was observed from 1300 h to 1730 h (Fig. 2). Female (both teneral and mature) abundance in the canopy

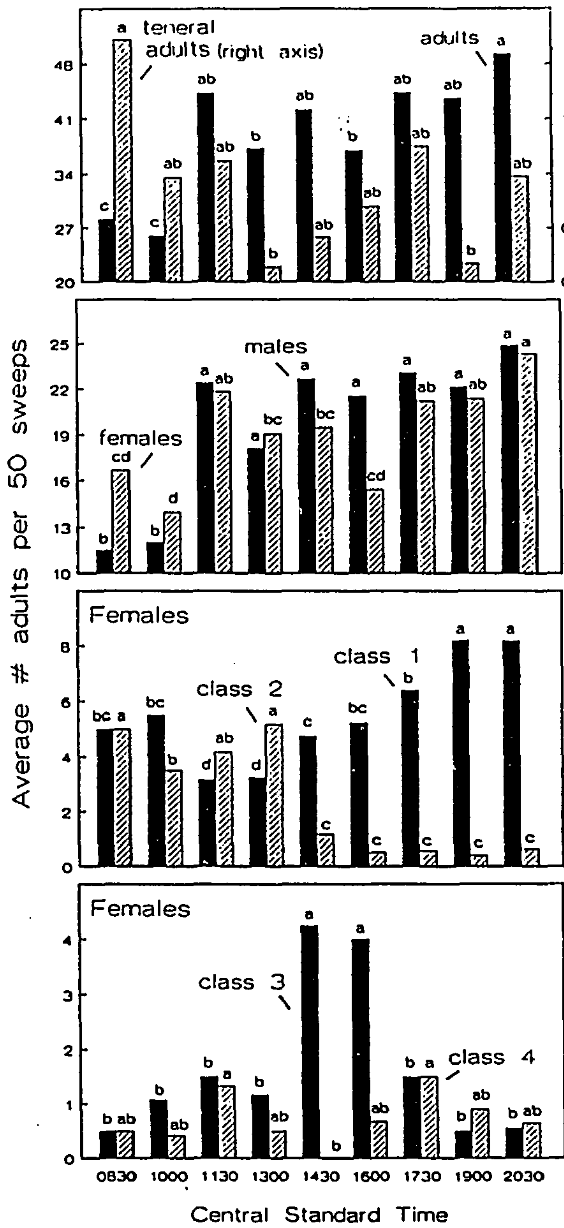


Fig. 2 Diurnal abundance of bean leaf beetle adults in soybeans on 21 July 1988 near Ames, Iowa. Means with the same letter (comparison among sampling times) do not differ significantly (P=0.05) as determined by Duncan's multiple range test (Duncan 1955).

declined significantly ($P<0.05$) during midafternoon, and the males remained constant. Class-1 female captures declined significantly ($P<0.05$) from 1000 h to 1130 h and exhibited a gradual and significant ($P<0.05$) increase from 1130 h to 1900 h. Class 2 captures were relatively constant from 0830 h to 1300 h, declined significantly ($P<0.05$) from 1300 h to 1430 h, and remained low through the rest of the sampling series. Class-3 captures were significantly ($P<0.05$) larger at 1430 h and 1600 h than at any other sample time. No significant ($P>0.05$) fluctuations in class-4 captures were detected.

DISCUSSION

Our results provide convincing evidence that two generations of the bean leaf beetle occur in central Iowa. Adults were first observed in alfalfa during late April to early May. Bean leaf beetle populations in alfalfa reached a maximum during mid-May and, in most fields, declined after soybean emergence in the vicinity. Adults disappeared from alfalfa by the first week of June. Information from Loughran and Ragsdale (1986) indicated that Minnesota bean leaf beetle populations in alfalfa were behind the populations sampled in this study by about 2 weeks. Adult abundance in Minnesota alfalfa peaked during late May to early June and lasted until late June.

In Iowa, overwintering adults colonized soybean fields immediately after seedling emergence, were most abundant during late May, and disappeared by the start of July. F_1 adults first emerged during late June and early July, peaked in mid-July to early August, and disappeared by mid- to late August. F_2 adults were present starting in August and were most abundant during late August to mid-September. After soybean senescence, F_2 teneral adults continued to emerge and remained in the field until they had matured sufficiently to migrate to alfalfa or overwintering habitats.

Adults in Iowa colonized alfalfa during August, after soybeans in the vicinity initiated maturation. Bean leaf beetle populations peaked during late September and disappeared by early October. In Minnesota, adults began leaving soybean fields for overwintering sites in mid-August (Loughran and Ragsdale 1986). In Louisiana, adults began movement from soybean to overwintering quarters during late July to early August (Payah and Boethel 1985).

The first females colonizing alfalfa during the spring in Iowa had undeveloped ovaries. Ovarian development occurred while beetles were in the alfalfa, with some females ready to lay eggs when soybeans appeared. Loughran and Ragsdale (1986) reported similar ovarian dynamics for bean leaf beetles in Minnesota. In Iowa, ovaries in F_2 females both in alfalfa and soybeans remained undeveloped.

Adult females in Iowa alfalfa and soybeans were more abundant than males from spring until the start of F_2 adult emergence. In most fields, neither sex of the F_2 adults dominated. Red females exhibited greater winter survivorship than yellow females, but no significant changes in red-to-yellow ratios in males were observed. Similar information for other regions is not available.

Bean leaf beetle phenology on soybean in North Carolina seemingly lags that observed in central Iowa by 3 to 4 weeks. Boiteau et al. (1980a) observed that overwintering generation adults in North Carolina were present in soybeans from late May or early June until early August. F_1 adults were observed from mid-July to early September, and F_2 adults were abundant from late August or early September to mid-October. In Minnesota, soybean bean leaf beetle populations sampled by Loughran and Ragsdale (1986) were 3-4 weeks behind the Iowa population. The Minnesota overwintering generation adults were present until mid-July. F_1 adults began emergence during mid-July and were most abundant during late August. Adult phenology in central Illinois also was usually behind that observed in Iowa by approximately 2 weeks (Waldbauer and Kogan 1976b). Overwintering adults in

Illinois were abundant during June and decreased to low levels in early July. F_1 adults were present from mid- or late July until the second or third week of August. F_2 adults were found during September and remained in the field until plants have completely matured.

Waldbauer and Kogan (1976b) suggested that soybean planting date affects the timing of bean leaf beetle adult abundance. This may explain why adult phenology on soybean in Iowa was ahead of that reported in North Carolina, Illinois, and Minnesota. Our soybean sampling fields were planted early so that seedlings appeared by early to mid May. This was done to assure sufficient beetle populations (Waldbauer and Kogan 1976b). The data provided from North Carolina, Illinois, and Minnesota were collected from fields in soybeans that emerged during late May or early June.

Our diurnal study revealed that adult captures in the soybean canopy were least during the early morning, seemingly correlated with the presence of dew on the canopy. In Illinois, beetle catches were least around noon, with peak activity around 1700 h (Kogan et al. 1974). Our study showed that female abundance in the canopy declines during midafternoon, while the male population remains constant. The decrease in female captures during the afternoon was caused by declines in females with partially developed ovaries. Females with fully developed eggs were actually more abundant during the afternoon, contradicting Kogan's speculation that increased ovipositional activity causes the female population in the canopy to decrease.

The diurnal study results indicate that optimal sampling time for the sweep net procedure depends on the type of data required. For total adult abundance, sampling after 1130 h is recommended. Sampling from 1730 h to

2030 h would provide reliable sex ratio information. An accurate estimate of female age structure, however, requires a series of samples taken at various times of the day. The fact that our results were interpreted from one sampling run is important to recognize. The significance of these results, therefore, should be weighed accordingly.

SECTION II. BEAN LEAF BEETLE HERBIVORY ON LEAF, STEM, AND POD COMPONENTS OF SOYBEAN

ABSTRACT

Soybeans in field cages were infested in two non-drought years (1986 and 1987) and one drought year (1988) with selected densities of adult bean leaf beetles, Cerotoma trifurcata (Forster), to ascertain the feeding behavior of this pest during late season (mid-August to mid-September). Pod surface injury, pod clipping, defoliation, and stem surface feeding occurred simultaneously. Regression analyses provided equations relating bean leaf beetle feeding days (area under bean leaf beetle density-time curve) to pod, leaf, and stem injury. These analyses indicated that each adult injured an average of 9.8 pods in the non-drought years and 3.6 pods in the drought year. Significant pod loss differences among treatments were detected only in 1988, with an average of 2.6 pods lost per bean leaf beetle. A significant trend in defoliation with increasing bean leaf beetle feeding days occurred in 1986 and 1987, with an average of 6.6 cm^2 of leaf tissue removed per adult. Regression analysis also indicated that an average of 5.8 to 7.2 stem lesions were caused per adult. Equations describing the relationships between various pod injury measurements also were determined.

INTRODUCTION

The occurrence of economically important late-season bean leaf beetle infestations in Iowa has been steadily increasing during the 1980s. Bean leaf beetle adults defoliate soybean plants; however, economic damage by this type of feeding is not common in most areas. During late season, as leaves mature, adults begin feeding on support and reproductive tissues. They injure pods by consuming the outer layer of the soybean pod, leaving a thin layer of tissue (endocarp) still covering the seed. This pod injury increases the vulnerability to excess moisture and secondary pathogens, particularly *Alternaria tenuissima* (Fries) Wiltsh., leaving seeds shrunken, discolored, and sometimes moldy (Shortt et al. 1982). Seed damage of this type is known to reduce market value (Paul 1989).

The beetles also consume the outer green tissue of stems. Injury on the main stem, branches, or leaf supports probably has little effect on plant productivity. Beetles, however, often feed on pod peduncles (structures joining the pod to the stem), thus clipping the pods or weakening the peduncle to allow pod drop during rain or strong winds. Late-season adult bean leaf beetle feeding on soybean, especially on reproductive and support components, has not been quantified. This study was undertaken to determine the relationship between bean leaf beetle adult density and late-season injury on soybean stem, leaf, and pod components.

MATERIALS AND METHODS

A field cage study was conducted during 1986, 1987, and 1988 in c.v. 'Corsoy 79' soybeans near Ames, IA, using a randomized complete block design, with four blocks in 1986 and 1987 and five blocks in 1988. Four cages (2x1m base, 1m tall) made of a fine-mesh Saran^{R} cloth were placed in each block on the plots one to three days before artificial infestation with adult bean leaf beetles. In 1987 and 1988, before cage placement, plant stands were thinned to 25 and 23 plants/m (0.76m row spacing), respectively.

Treatments included three levels of artificial beetle infestation (1, 4, and 7 adults/plant in 1986; 2, 6, and 12 adults/plant in 1987; and 6, 12, and 18 adults/plant in 1988). One cage in each block was not artificially infested so that injury by local bean leaf beetle populations could be monitored. A plot in each block was not caged to ascertain cage effects on injury. Cages were infested on 15 August 1986, 9 August 1987, and 13 August in 1988 with field-collected bean leaf beetle adults. At infestation soybeans were in stage R5 (Fehr et al. 1971) in 1986 and in stage R6 in 1987 and 1988.

Destructive plant samples were taken from within the cages and from uncaged plots at 7-10 day intervals after infestation until soybeans matured. Each sample consisted of 2 plants/plot for non-harvest 1986 dates and 5 plants/plot for the remaining sample dates. The number of pods injured by bean leaf beetle adults, the number of bean leaf beetle pod lesions, and the number of pods not injured by bean leaf beetles were recorded for each node of each soybean plant. Only pods that were 5mm or longer were counted. The number of stem lesions per plant also was recorded for 19 August 1987 and for all 1988 samples. Pod and leaf tissues removed by bean leaf beetle feeding were determined by photocopying injured pods and leaves, blackening the injured areas on the photocopied images, and measuring the darkened area by a Delta-T^{R} area meter (Delta-T Devices, LTD, Burwell, Cambridge, England). Rainfall was measured by a rain gauge located within 100 m of the study area.

Quantifying Bean Leaf Beetle Feeding Days (BLB-days)

In 1987 a fifth cage was placed in each block and infested with 6 beetles/plant to monitor beetle mortality. Three days after infestation and at ten-day intervals thereafter bean leaf beetle numbers were determined by visual inspection of five plants in each mortality check cage. Percentage mortality through time was estimated from these data. Subsequently, this relationship was used to estimate the decline of bean leaf beetle numbers in the cages for 1986, 1987, and 1988. To determine beetle feeding days (BLB-days), bean leaf beetle density was plotted against days after infestation for each treatment in each year and the area under these curves calculated.

Natural bean leaf beetle populations in the vicinity of the field cages were monitored by sweep net to estimate bean leaf beetle abundance in the uncaged and caged checks. Eight samples of 40-(1987) and 50-(1988) sweep sampling units each were collected every 3-4 days throughout the study period. Counts were converted to absolute population estimates by following the procedure of Rudd and Jensen (1977).

Statistical Analysis

Relationships between injury parameters, and BLB-days and interrelationships among various pod injury parameters, were investigated by using regression analysis. Cage effects were evaluated by including a dummy variable in some regression models (SAS Institute 1985, pp. 70-72). In some of the analyses that used data pooled from more than one sample, a time by independent variable interaction term was included to quantify variation among regression coefficients.

RESULTS

Pod Injury/BLB-day Relationships

Rainfall amounts were similar in 1986 and 1987, but a major drought occurred in 1988. Because plants in all plots showed considerable drought-stress symptoms in 1988, data from that year were often analyzed separately.

The average number of injured pods in all treatments in 1986 increased after infestation until the 5 September sample, then remained generally constant until harvest (Fig. 3). In 1987 the number of injured pods in all treatments increased from infestation to 19 August, then decreased from 19 August to harvest (Fig. 3). The decrease in injured pod counts probably was caused by bean leaf beetle pod clipping.

Regression analyses revealed that a significant ($P<0.05$) linear relationship existed between number of injured pods and BLB-days for all post-infestation samples in 1986 and 1987. A significant ($P<0.01$) quadratic component also was detected for the 22 August 1986 and harvest 1986 samples. The first post-infestation sample data from 1986 and 1987 were chosen to represent the injured pod - BLB-day relationship in the respective years. Data from remaining 1986 and 1987 samples were not included because pod clipping by adults probably had increasing influence on the injured-pod/BLB-day relationship for samples taken later in the season. The 1988 data also were not included because of the drought symptoms observed. The BLB-day regression coefficient for 1987 (Table 2) is significantly greater than the regression coefficient for 1986 (least

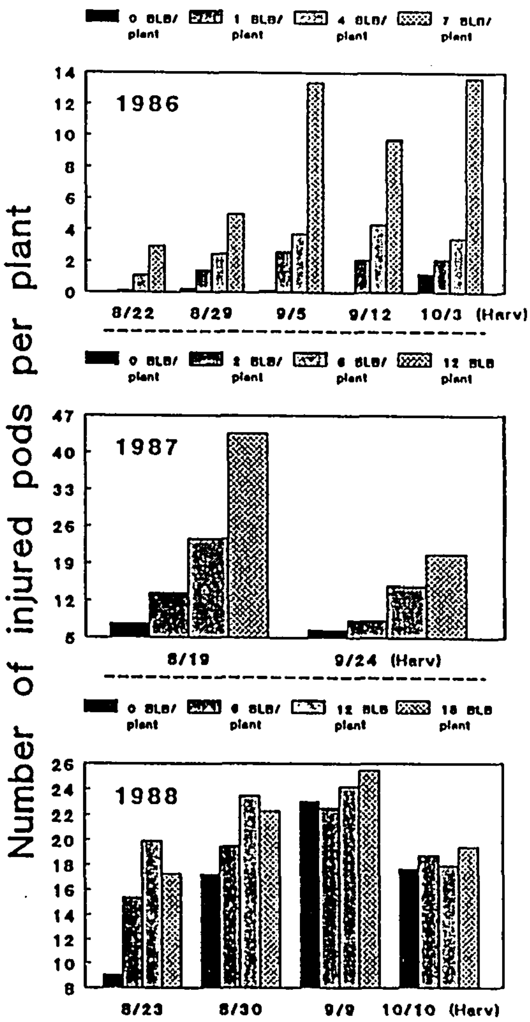


Fig. 3 Injured pod means for the caged plot treatments (1986-1988). BLB/plant = number of bean leaf beetle adults per plant placed in cages at infestation date.

Table 2. Regression analyses for 1986/1987 (non drought years) and 1988 (drought year) of relationships between plant injury parameters and bean leaf beetle feeding days (BLB-days) using plot means

Year(s)	Sample dates[a]	Dependent variable	BLB-day coeff. ± SEM[b]	Year coeff. ± SEM[c]
1986	22 Aug.	# injured pods	0.120 ± 0.020	
1987	19 Aug.	# injured pods	0.494 ± 0.061	
1988	23 Aug.[e]	# injured pods	0.184 ± 0.036	
1986/1987		# pods	No significant trends	
1988	23 Aug. 1988	# pods	-0.125 ± 0.047	
1986/1987 pooled	29 Aug. 1986 & 19 Aug. 1987	BLB-type leaf injury[d]	0.329 ± 0.088	22.4 ± 3.9
1988		BLB-type leaf injury	No significant trends	
1987	19 Aug.	# stem lesions	0.357 ± 0.036	
1988	all non harvest samples	# stem lesions	0.345 ± 0.053	

[a]Sample dates chosen to represent the injury - BLB-day relationship for the designated year.

[b]Regression coefficient for bean leaf beetle feedings days. SEM = standard error of the mean.

[c]Coefficient of year dummy variable. SEM = standard error of the mean.

[d]Injury typically caused by bean leaf beetle feeding, characterized by rounded holes.

[e]* = $P<0.05$; ** = $P<0.01$.

r^2	N	
0.690	20	**[e]
0.822	20	**
0.572	25	**
0.264	25	*
0.644	40	**
0.868	20	**
0.388	75	**

significant difference (LSD) = 0.0365,P<0.05,df=21). The 1987 coefficient (0.49 injured pods/BLB-day) was chosen to represent bean leaf beetle feeding rates during non-drought years because a wider range of infestation levels were used in 1987 than in 1986.

Multiplying the 1987 coefficient by the length of the bean leaf beetle feeding period (20 days) provides an estimate of the average injury caused by an adult (9.8 pods/beetle). Longevity of this insect in the laboratory has ranged from 29.5 days (Eddy and Nettles 1930) to 41.0 days (Herzog et al. 1974). A twenty-day feeding period was selected, however, because Isely (1930) reported that this insect does not actively feed more than three weeks under approximate field conditions. Also, in our study, only 8 percent of the beetles in the mortality check cages were foraging at 24 days post infestation (adults of varying ages were used for infestation).

In 1988 a significant linear (P<0.05) relationship between number of injured pods and BLB-days was observed only for the first sample (23 August). For this sample the 0-, 6-, and 12-beetles/plant treatments exhibited a significant (P<0.01) linear trend with a considerable decline in injured pods from the 12- to the 18-beetles/plant treatments (see Fig. 3). The differences in injured-pod counts among treatments decreased with time, seemingly because the 12- and 18-beetles/plant treatments exceeded the linear portion of the injury curve. In 1988, the non-linear injury segment probably occurred at lesser insect densities in 1988 than the other two years because total pod counts were relatively less (uncaged control - 65.0 in 1986, 63.4 in 1987, 42.1 in 1988 at first post-infestation sample). This decreased pod count in 1988 probably was the result of drought stress (Mederski et al. 1973). The regression coefficient from the 23 August

1988 analysis (all but the greatest infestation treatment) was used to estimate the linear segment of the injured pod - BLB-day relationship in 1988. The coefficient from this analysis indicates that an average of 0.184 pods/BLB-day (3.6 pods/bean leaf beetle) were injured during 1988.

Injured-pod counts in the uncaged plots did not deviate significantly ($P>0.05$) from the caged check plots for any of the samples dates.

Pod Clipping

No significant ($P>0.05$) relationship between pod counts and BLB-days was detected for any 1986 or 1987 sample. In 1986, mean pod counts from all artificial infestations were greater than the caged check from infestation to the 5 September sample (Fig. 4). The sole exception was the 4 beetle/plant treatment on 29 August. This difference in treatments declined after 5 September, with all infested-cage means falling below the caged-check mean by harvest. Most soybeans were in stage R6 (full seed) from infestation to 5 September, with maturation (stage R7) beginning soon after 5 September. If these trends are indicative of actual soybean response, then these plants tended to compensate for pod injury before maturation by setting or keeping more pods than those lost by beetle feeding on peduncles. After maturation, the plant would seem to stop pod compensation, and pod loss from beetle injury could explain a reduction in pod counts at harvest. Differences of total pod counts between the check and infested treatments on 19 August 1987 were similar to the first 3 samples in 1986 (Fig. 4). Harvest 1987 pod count differences, however, were unlike those at harvest 1986 because at harvest 1987 the number of

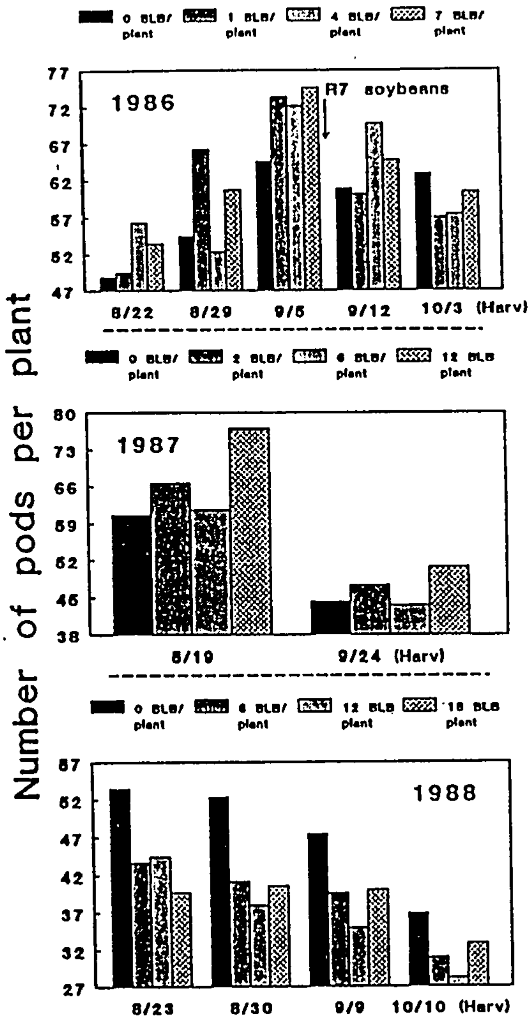


Fig. 4 Total pod means for the caged plot treatments (1986-1988). BLB/plant = number of bean leaf beetle adults per plant placed in cages at infestation date.

pods, for unknown reasons, was still greater in the infested cages than in the caged check.

The suspected soybean compensatory response was not observed in 1988, possibly because drought conditions and considerable injury by a large local twospotted spider mite, Tetranychus urticae Koch, population had weakened plants (Higley and Wintersteen 1989). All infested cage treatments had appreciably lower pod counts than the caged check for all 1988 samples (Fig. 4). A significant ($P<0.05$) inverse linear relationship was detected between number of pods and BLB-days at the 23 August 1988 sample date (Table 2). No significant ($P>0.05$) linear relationship was detected for the remaining 1988 sample dates, probably because injury in the infested cages exceeded the linear portion of the pod-injury/BLB-day relationship. Also, an appreciable emergence of local beetles in the study area (peaking at 5 beetles / sweep during late August) forced beetle densities in all treatments into the plateau region of the injury curve, eliminating treatment differences.

The regression coefficient (Table 2) from the 23 August analysis is probably the best estimate of the linear segment of the pod-loss/BLB-day relationship because no curvilinear effect was exhibited with these data. Assuming no plant compensation during 1988, an average of 0.13 pods/BLB-day (2.6 pods/bean leaf beetle) were lost by feeding on pod peduncles.

Total pod counts in the uncaged plots differed significantly ($P<0.05$) from the caged-plot trend for only the 22 August 1986 and 23 August 1988 samples. The uncaged-check pod count mean was greater than the caged-check mean on 22 August 1986 and less than the caged-check mean on 23 August 1988.

Defoliation

Significant (P<0.05) linear trends were detected between bean leaf beetle-type leaf injury (rounded holes) and BLB-days for all 1986 and 1987 non-harvest samples. The data from the first post infestation samples for which leaf injury data were collected in 1986 (29 August) and 1987 (19 August) were pooled with a year variable included. Later sample dates were not included because increased leaf drop altered feeding rate estimations. The BLB-day coefficient from this regression, 0.33 cm^2/ BLB-day (Table 2), multiplied by 20 days/beetle gives a leaf consumption rate of 6.6 cm^2/beetle. No significant relationships were detected between leaf feeding and BLB-days in 1988 (Table 2), possibly because drought stress decreased leaf attractiveness to the beetles. No significant (P>0.05) differences in defoliation between the caged and uncaged checks were detected.

Stem Lesions

A significant (P<0.01) linear relationship between number of stem lesions and BLB-days was indicated for 19 August 1987 (only sample in 1987 for which stem lesions were recorded). The regression coefficient from this analysis (Table 2) indicates that an average of 0.36 stem lesions were produced per BLB-day (7.2 stem lesions/bean leaf beetle) in 1987. Significant linear trends also were observed for all pre-harvest samples in 1988, and the pooled regression coefficient (Table 2) of these samples is

0.29 stem lesions/BLB-day or 5.8 stem lesions/bean leaf beetle, which is appreciably less than the 1987 coefficient.

Pod-injury Interrelationships

Strong linear relationships were detected between all combinations of number of pod lesions, number of injured pods, and injured-pod area. A significant ($P<0.01$) quadratic component was obtained for all relationships for pooled data from all sampling dates (Table 3). These quadratic equations indicate that, at lesser adult densities, the bean leaf beetle causes fewer pod lesions per pod, less injured-pod area per pod, and greater injured-pod area per pod lesion than at greater adult numbers.

The number of injured pods at the top four nodes of the soybean plant main stem is highly correlated ($P<0.01$) to the number of injured pods per entire plant in all but the last two 1988 sample dates. Data for 1987 and 1988 were pooled without 1986 data because the ratio of injured pods in the top 4 nodes to injured pods per plant was considerably less in 1986 than for the other two years. Pooled regression (Table 3) coefficients indicate that, on the average, one third of the injured pods per plant were located in the top four nodes in 1986. In 1987/1988, a fourth of the injured pods per plant were located in the top four nodes.

Table 3. Regression analysis of pod injury interrelationships using plot means

Data in analysis	Dependent variable	Independent variable	slope $\pm$ SEM[b]	quad. coeff. $\pm$ SEM[c]
All data pooled	# pod lesions	# injured pods	1.8 $\pm$ 0.3	0.066 $\pm$ 0.007
"	injured pod area (mm^2)	# injured pods	20.7 $\pm$ 2.6	0.523 $\pm$ 0.070
"	injured pod area (mm^2)	# pod lesions	10.1 $\pm$ 0.5	-0.006 $\pm$ 0.002
1986 pooled	injured pods per plant	injured pods in top 4 nodes	3.1 $\pm$ 0.2	
1987/1988 pooled	injured pods per plant	injured pods in top 4 nodes	4.1 $\pm$ 0.4	

[a] * = $P<0.05$; ** = $P<0.01$.

[b] regression coefficient $\pm$ standard error of the mean.

[c] quadratic coefficient of the independent variable $\pm$ standard error of the mean.

r^2	N	
0.887	220	**[a]
0.876	220	**
0.890	220	**
0.639	240	**
0.597	240	**

DISCUSSION

Based on caged and uncaged comparisons, artificially infested field cages provided a reasonable means of estimating the quantitative aspects of bean leaf beetle feeding. Injury amounts in the uncaged check plots rarely differed significantly ($P<0.05$) from those measured in the caged checks.

Our studies showed that the bean leaf beetle has the potential to feed heavily on leaf, stem, and reproductive components of soybean during late season. Pod clipping and pod surface feeding are economically more important because the former directly decreases pod yield and the latter influences soybean quality. During non-drought years, soybeans seemingly compensated for pod clipping, but soybeans under drought stress seemed to lose the compensatory ability. Also, the number of pods injured per bean leaf beetle was less during 1988 (drought year) than during 1986 or 1987 (non-drought years), possibly because pod counts were reduced in 1988 or drought symptoms had reduced nutritional quality of soybean pod tissues.

Waldbauer and Kogan (1976a) determined that the bean leaf adult comsumes 1 cm^2/day. At this feeding rate, a bean leaf beetle, with a life span of 20 days, would consume 20 cm^2 in its lifetime. The difference in consumption rates determined by Waldbauer and Kogan and those calculated in our study (6.58 cm^2/beetle) may be explained by the fact that, during late season feeding, beetles supplement their leaf diet with tissue from other plant components.

Timing of F2 adult appearance in the field may greatly affect the amount of feeding on any or all of the soybean components. Our study concentrated on a warm-year scenario in which F2 adults emerge during early- to mid-August, and numbers peak during late August or early September (Section I). In other scenarios for cool years, F2 adults do not emerge until late August or early September and peak during mid- to late September, after leaf senescence, thus reducing adult injury potential.

In Iowa and perhaps other areas of the North Central United States, the F1 generation may be an economic problem in some years with both pod and foliar injury likely, but injury proportions of these soybean components may differ considerably from those observed in this study. F1 adults begin emerging during late June or early July and numbers peak from mid- to late July (Section I). During this time the soybean plant has an increased ability to compensate for stress (Mederski et al. 1973). Also, the proportion of F1-adult leaf feeding relative to the other soybean components might be greater because more young leaf tissue is available.

SECTION III. SOYBEAN SEED YIELD AND QUALITY REDUCTION BY BEAN LEAF BEETLE POD INJURY

ABSTRACT

Soybeans in field cages were infested with bean leaf beetle adults to determine the effect of late season pod feeding on soybean seed yield and quality. Regression analysis of yield parameters against bean leaf feeding days (area under bean leaf beetle-density/time curve) revealed that a 3.06 kg/ha yield loss was caused by each bean leaf beetle per square meter. Damaged seed weight as determined from data provided in official grain-grade reports was regressed against the number of injured pods at harvest. Information from this analysis indicated that 685 to 1076 injured pods/m^2 were necessary for sufficient seed damage to incur an economic discount. Official damaged seed weight per injured pod seemingly was dependent on late-season rainfall. The number of seeds with greater than 50 percent of their surface tissue darkened was more consistently correlated with the number of injured pods than the number of seeds with less than 50 percent darkened tissue or the number of seeds that were lightly discolored or shriveled and without darkened tissue.

INTRODUCTION

The bean leaf beetle adult is a common foliar pest of soybean throughout the eastern half of the United States (Kogan et al. 1980). In several areas, during late season, this insect supplements its leaf diet by feeding on the outer green tissue of soybean stems and pods (Section II). Stem feeding includes injury to peduncles (structures joining pods to stems), which causes pods to dislodge from plants, thus reducing soybean yield. Pod injury includes removal of all pod-wall tissue except the inner-most layer (endocarp), allowing secondary fungal pathogens, primarily *Alternaria tenuissima* (Fries) Wiltsh., to attack the seeds and inflict considerable damage (Shortt et al. 1982) (Fig. 5). Seed-quality reduction in bean leaf beetle-infested fields often is severe enough to incur economic penalties (Paul 1989). *A. tenuissima* is routinely isolated from green soybean tissue throughout the season and infects seeds only through pod wounds. Shortt et al. (1982) isolated *A. tenuissima* also from surface-sterilized bean leaf beetle heads and abdomens, suggesting that the beetles increase pathogen dissemination.

Reports of economic bean leaf beetle infestations during late season have steadily increased since the early 1980s, prompting research to develop late-season bean leaf beetle-management guidelines. The specific goal of this study was to quantify the effect of bean leaf beetle adult feeding on soybean yield and seed quality.

Fig. 5. Bean leaf beetle pod injury and resultant seed damage.

MATERIALS AND METHODS

Artificial infestations were established in 'Corsoy 79' soybeans near Ames in 1986, 1987, and 1988 (Section II). Bean leaf beetle adults, collected in the field, were placed in field cages (2 x 1-m base, 1-m tall) at various densities (1, 4, and 7 beetles/plant in 1986; 2, 6, and 12 beetles/plant in 1987; and 6, 12, and 18 beetles/plant in 1988) during mid-August when soybeans were at stages R5 to R6 (Fehr et al. 1971). Destructive plant samples (5 plants/sample in 1986 and 1988; 8 plants/sample in 1987) were taken from all plots at harvest. The number of injured pods was recorded for each plot. Bean leaf beetle feeding days (BLB-days) were estimated by monitoring adult abundance in designated cages in 1987 and calculating the area under the bean leaf beetle-density/time curve (Section II).

In 1987 and 1988, a small plot thresher was used to collect seed from plants that remained after plant sample removal (threshed seed samples). Seed from the individual plants and the threshed seed samples were counted and weighed. These data were pooled to provide total seed weight per plant and number of seeds per plant in each plot. Seed weights were measured when samples were at approximately 11.5 percent moisture. Seed quality was evaluated by segregating seed into the following categories (Fig. 6): 1) greater than fifty percent of seed surface with darkened tissue, 2) less than fifty percent of seed surface with darkened tissue, 3) lightly discolored or shriveled seed without darkened tissue, and 4) all seed not in first three categories.

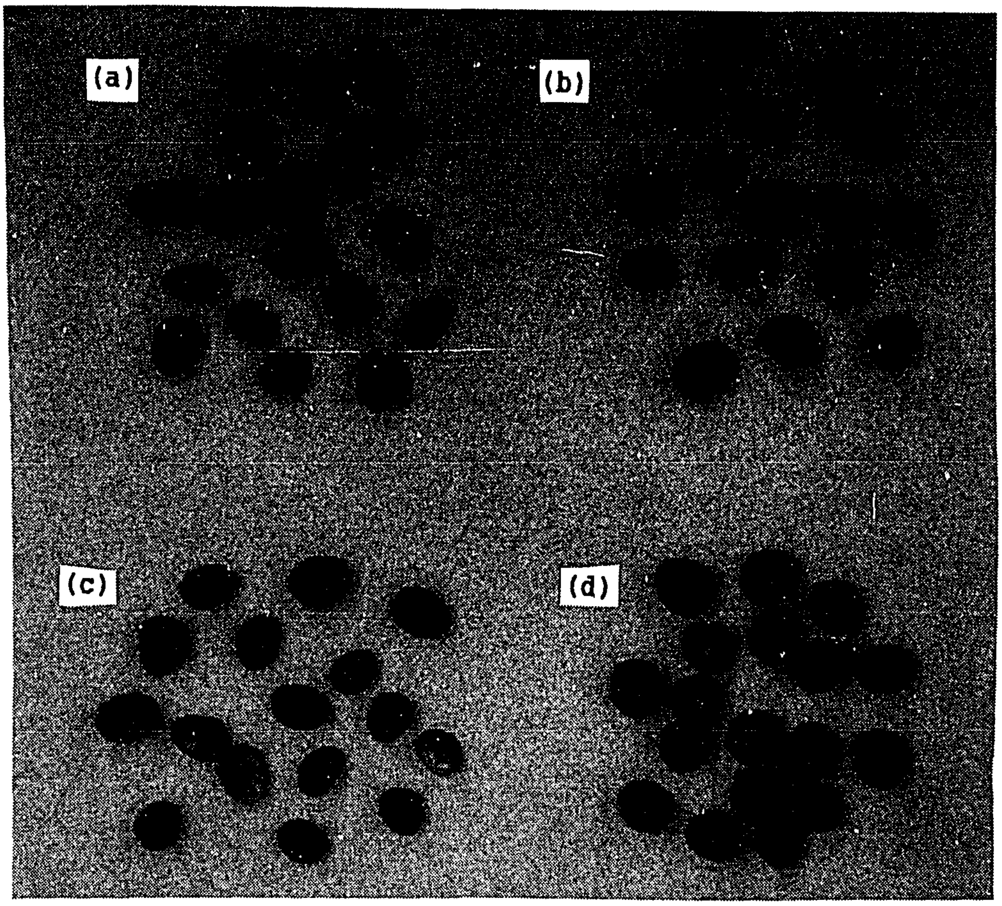


Fig. 6 Soybean seed categories used to quantify the effect of pod-surface feeding on seed damage. Category 1 seeds (a) have greater than 50 percent of their surface with darkened tissue. Category 2 seeds (b) include those with less than 50 percent of their surface with darkened tissue. Category 3 seeds (c) are lightly discolored or shriveled with no darkened tissue. Category 4 (d) has the remaining seeds and contains mostly healthy seed.

Seed samples were sent to the Eastern Iowa Grain Inspection and Weighing Service, Inc., Davenport, Iowa, to obtain official estimates of percent damaged seed. This damaged seed classification is one of a few parameters that is used in grain marketing to determine grain grades and values (Agricultural Marketing Service 1970). For this study, official damaged-seed weight was calculated through multiplying percent-damaged seed by seed weight. Damaged-seed weight is more useful in economic injury level calculations because, unlike percent-damaged seed, damaged-seed weight does not depend on seed yield. Precipitation was measured by using a rain gauge located within 100 m of the study area.

Statistical Analysis

Regression analysis was used to determine the effect of bean leaf beetle feeding on soybean seed yield and quality. The bean leaf beetle-feeding/yield relationship was determined by regressing seed weight against BLB-days. The relationship between weight per seed and number of injured pods was analyzed similarly to determine if deterioration of seed in injured pods is responsible for an appreciable proportion of yield loss. Similar analyses were conducted to ascertain the effect of pod injury on soybean seed quality. Here, official damaged seed weight and the number of seeds in each seed damage category were regressed against the number of injured pods. A dummy variable was included to detect any significant cage effects on the above relationships. Analyses using data pooled for more than one year contained a year-by-independent-variable-interaction term to test for differences in regression coefficients among years.

RESULTS

Seed Yield

No significant (P>0.05) linear relationship between harvest seed weight and BLB-days was detected for individual 1986, 1987, or 1988 analyses (Table 4). In all years, average seed weight per plant decreased linearly from the uninfested cage to the second infestation level and then increased for the greatest infestation rate (Fig. 7). Similar trends were detected for pod counts in 1988 (Section II). This suggests that increased insect pressure possibly triggered a plant compensation response. A quadratic component added to the 1986, 1987, and 1988 analyses increased the correlation coefficient but did not explain a significant (P>0.05) proportion of the variation (Table 4).

Seed yield dropped 20 percent in 1987 and 49 percent in 1988 from the caged check to the second greatest infestation level. This level of yield reduction would encompass the range of damage important for bioeconomic analysis. Therefore, linear regressions were conducted on the 1987 and 1988 data with the greatest infestation treatment data removed. The 1986 data were excluded because seed weight for that year included only that seed collected from the plant samples. Correlation coefficients increased for both years, with a significant relationship detected for 1988. A BLB-day/year interaction term indicated no significant (F=2.76, P>0.05, df=3,46) difference between 1987 and 1988 regression coefficients. Thus, the 1987 and 1988 data (without the greatest infestation treatments) were pooled and analyzed with a year dummy variable (accounts for y-intercept

Table 4. Regression analysis of the seed weight (g) - bean leaf beetle feeding day relationships with data averaged by plot

Year	Linear coefficient ± SEM[a]	Quadratic coefficient ± SEM[b]
1986	-0.0239 ± 0.0321	
1987	-0.00449 ± 0.00769	
1988	-0.00821 ± 0.00444	
1986	-0.233 ± 0.112	0.00320 ± 0.00143
1987	-0.0729 ± 0.0313	0.000570 ± 0.000254
1988	-0.0437 ± 0.0174	0.000172 ± 0.0000819
1987 w/o greatest infestation	-0.0354 ± 0.0167	
1988 w/o greatest infestation	-0.0139 ± 0.00593	
1987 & 1988 w/o greatest infestation	-0.0153 ± 0.00563	

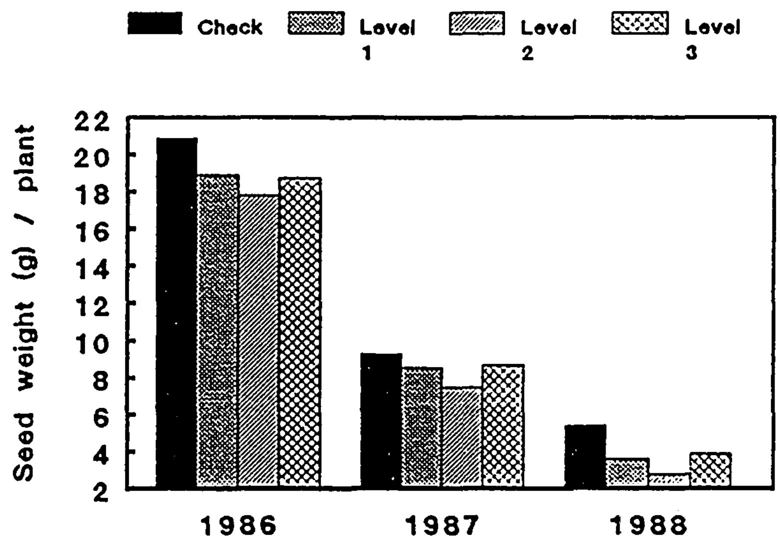
[a]Linear regression coefficient ± standard error of the mean.

[b]Quadratic regression coefficient ± standard error of the mean.

[c]Coefficient of the year variable ± standard error of the mean.

[d]* = $P < 0.05$; ** = $P < 0.01$.

Year coefficient $\pm$ SEM[c]	r^2	N	
	0.237	20	
	0.054	20	
	0.146	25	
	0.277	20	
	0.281	20	
	0.301	25	
	0.277	16	
	0.296	20	*[d]
-3.53 $\pm$ 0.452	0.765	36	**



Level 1 = 1(1986), 2(1987), and 6(1988) bean leaf beetles/plant placed in cages at infestation.

Level 2 = 4(1986), 6(1987), and 12(1988) beetles/plant.

Level 3 = 7(1986), 12(1987), and 18(1988) beetles/plant.

Fig. 7 Harvest seed weight means for caged plot treatments (1986-1988).

differences between years). Both BLB-days and the year variable accounted for a significant ($P<0.05$) proportion of the variation. Seed weight per plant did not differ significantly ($P>0.05$) between the uncaged and the caged check for any year.

Weight per seed (all seed categories combined), weight per seed of healthy seeds (category 4), and number of seeds per plant individually were not significantly ($P>0.05$) related to BLB-days for any harvest sample. Thus, individual proportions of seed weight loss from pod clipping or seed damage in surface-injured pods could not be determined.

Soybean Seed Quality

Regression analysis revealed significant ($P<0.05$) linear relationships between weight of damaged seed (determined from official percent damaged seed reports) and number of pods injured by bean leaf beetles for all harvest seed samples (Table 5). The 1987 regression coefficient was significantly (least significant difference - LSD=0.00142, $P<0.05$, df=21) greater than regression coefficients for 1986 and 1988. Also, the regression coefficient for 1988 was greater than the 1986 coefficient, but was not significant (LSD=0.00142, $P>0.05$, df=21). Total rainfall from infestation to harvest paralleled the damaged-seed/injured pod coefficients. Rainfall during this period was greatest in 1987 (22.8 cm) and least in 1986 (13.0 cm), with 1988 rainfall intermediate (17.8 cm). Seemingly, increasing moisture on the injured pods encouraged the dissemination and growth of fungi. Damaged-seed-per-injured-pod values

Table 5. Regression analysis of damaged seed parameters versus injured pod counts with data averaged by plot

Year	Dependent variable	Linear[a] coefficient ± SEM
1986	official damaged seed weight(g)	0.00483 ± 0.00175
1987	" " " "	0.00759 ± 0.00179
1988	" " " "	0.00575 ± 0.00255
1986	number of category 1 seed	0.219 ± 0.0283
1987	" " " " "	0.204 ± 0.0304
1988	" " " " "	0.125 ± 0.0415
1986	number of category 2 seed	0.0960 ± 0.0467
1987	" " " " "	0.228 ± 0.0437
1988	" " " " "	0.302 ± 0.0714
1986	number of category 3 seed	0.0399 ± 0.0366
1987	" " " " "	-0.0252 ± 0.0995
1988	" " " " "	0.243 ± 0.0573

[a]Regression coefficient of number of injured pods variable ± standard error of the mean.

[b]* = $P < 0.05$; ** = $P < 0.01$.

r^2	N	
0.300	20	*[b]
0.499	20	**
0.188	25	*
0.770	20	**
0.715	20	**
0.281	25	**
0.190	20	
0.602	20	**
0.438	25	**
0.062	20	
0.004	20	
0.438	25	**

were not significantly (P>0.05) different between the caged and uncaged plots.

The relationship between the number of damaged seed classified by our guidelines, and the number of injured pods at harvest differed appreciably among years and among the various damage categories. A significant (P<0.01) linear trend was detected for 1986, 1987, and 1988 between the number of damaged seed in category 1 (seed with greater than 50 percent of the seed surface darkened) and the number of injured pods at harvest. The 1988 regression coefficient was significantly (LSD=0.0235, P<0.05, df=21) less than 1986 and 1987 coefficients, with no significant (P>0.05) difference between the 1986 and 1987 coefficients. The rainfall from infestation to harvest seemingly had less impact on the category-1 seed/injured-pod relationship than on the official damaged seed weight/injured pod relationship. The drought stress incurred by the soybeans in 1988 possibly was a more influential factor.

Regression analysis revealed significant (P<0.05) trends between category-2 seed (less than 50 percent of seed surface darkened) and the number of injured pods at harvest for 1987 and 1988 but not for 1986. The 1988 regression coefficient was significantly (LSD=0.0385) greater than the coefficient for 1987.

A significant (P<0.05) relationship between the number of category 3 seed (lightly discolored or shriveled without brown or black tissue) and the number of injured pods at harvest was detected only for 1988. The only damaged seed - injured pod relationship that differed significantly (P<0.05) between caged and uncaged plots was the category 2 - injured pod comparison for 1986 and 1988. Uncaged values, however, were greater in 1986 and less in 1988 than the caged-plot trend.

DISCUSSION

Artificial infestation of field cages was an effective method for determining the effect of bean leaf pod injury on seed yield and quality. The data from this study indicate that bean leaf beetle adult injury has a significant impact on soybean seed yield and quality. Seed weight per BLB-day, official damaged seed weight per injured pod, and the number of seeds in the various damage categories were rarely significantly ($P<0.05$) different between the caged and uncaged plots.

Unit conversion of the regression coefficients provided in this study give useful information concerning seed yield and quality losses related to bean leaf beetle feeding. The seed yield-loss/BLB-day relationship indicated that 0.0153 g of seed weight were lost for each BLB-day. Multiplying this coefficient by the length of a bean leaf beetle feeding period of 20 days (Section II) indicates that a 0.306-g seed-weight loss is caused by each bean leaf beetle. One adult per square meter would result in a 3.06 kg/ha loss. In fields planted as those in our study, with a 0.76m (30 in.) row spacing and 25 plants/row-m (7.6 plants/row-ft.), a 101 kg/ha seed-yield decrease would be caused for each bean leaf beetle per plant.

The discount schedule for yellow soybeans, as determined by Archer Daniels Midland Co., Des Moines, Iowa, provides guidelines by which several elevator operators in Iowa determine the value of each unit of soybean grain. Other states acquire scheduling in a similar manner. This schedule suggests that grain value should be discounted when two percent damaged seed (determined according to Federal grain grading guidelines) is exceeded. If, for example, a field yields 2600 kg/ha (40 bu/acre), two percent of this yield or 52 kg/ha (0.80 bu/acre) damaged seed would need to be exceeded to incur a value discount. Therefore, according to the damaged-seed /injured pod coefficients, 685 (1987) to 1076 (1986) injured pods/m^2 would be needed, at harvest, for a value discount. In a field with a 0.76m row spacing and 25 plants/m, 36.1 (1987) to 56.6 (1986) injured pods/plant would have been the critical value.

The coefficients describing bean leaf beetle feeding versus seed yield or seed quality are probably subject to other plant and environmental characteristics. For example, results from this study suggest that seed yield may depend on the ability of the soybean plant to compensate for injury. Also, our data indicate that rainfall during the period from the start of bean leaf beetle pod feeding until harvest is an important factor in determining the severity of seed damage in bean leaf beetle-injured pods. Also, other important characteristics affecting seed quality might include the strength of pod tissue, the integrity of the seed coat, the stage of seed development, and the resistance of seed to damage from exposure and infection by fungi (Shortt et al. 1982). Quantifying the effects of any of these factors will increase understanding of seed damage in bean leaf beetle infested fields.

SECTION IV. ECONOMIC INJURY LEVELS, POPULATION DISPERSION, AND SEQUENTIAL COUNT PLANS FOR THE BEAN LEAF BEETLE ON SOYBEANS DURING LATE SEASON

ABSTRACT

Economic-injury level equations were determined for late-season bean leaf beetle pod injury. Tables are provided that contain economic-injury levels based on adult and injured-pod counts for several combinations of pest-management costs and crop-market values. Analyses revealed that economic-injury levels based on seed-yield loss are exceeded before economic penalties are incurred from damaged seed in surface-injured pods. Guidelines for economic thresholds were also provided. Bean leaf beetle adult and injured-pod dispersion was determined using Iwao's regression and Taylor's power law. Both analyses indicated that the adults are significantly aggregated, but injured pods are randomly distributed. Sequential count plans were developed for bean leaf beetle-adult and injured-pod sampling.

INTRODUCTION

The importance of late-season bean leaf beetle injury to soybean has increased steadily during the 1980s (Paul 1989). Adults feed on almost all green tissue on the soybean plant, including leaves, stem surface, outer layer of pods, and peduncles (structure connecting pods to stem) (Section II). The economic value of a soybean crop is reduced most by peduncle feeding (pod clipping) and by seed deterioration in surface-injured pods. Current economic-injury levels are nominal (i.e., based on the experience of pest managers). Nominal thresholds are useful in that they provide guidelines for management strategies where no guidelines were available. However, many of these thresholds may not reflect the true injury/damage relationship. Also, some are static and do not account for changes in management costs and crop market values. An artificial-infestation study, discussed in Section III, determined the injury/damage relationship for the bean leaf beetle during late season. This information forms the basis for the calculation of economic-injury levels for this pest.

Economic-injury levels are useful, however, only if guidelines for accurate assessment of insect density or density indices are available. This requires an understanding of the dispersion patterns exhibited by the insect. Boiteau et al. (1979d) and Kogan et al. (1974) calculated several dispersion indices for bean leaf beetle adults and found that these parameters generally indicated a significant departure from randomness, but with only a slight degree of aggregation. Iwao's (1968) regression is a dispersion analysis method commonly used to provide a functional relationship between mean and variance for calculation of sequential count plans. Boiteau et al. (1979d) used this procedure to develop sequential count plans for the bean leaf beetle adult.

Bechinski et al. 1983 calculated both Iwao's regression and Taylor's (1961) power law on the same set of green cloverworm larval data. They used the coefficients from the analysis that explained the greater proportion of the variation for calculation of sequential count plans. Taylor's power law has been calculated for bean leaf beetle adults by Kogan et al. (1974), however, no reports are available that describe a comparison of this analysis with Iwao's regression.

Assessing pest density by using population indices may be preferred to sampling the insect directly. Development of a sampling plan for these indices also requires dispersion analysis. No information concerning dispersion or sampling plans for late season pod injury by the bean leaf beetle, however, has been reported.

This study was initiated to determine economic-injury level equations based on bean leaf beetle adult counts and population indices. Also, the dispersion patterns of Iowa bean leaf beetle populations and the pods they injure were ascertained. Comparisons of Iwao's regression and Taylor's power law were made and sequential count plans developed.

MATERIALS AND METHODS

Economic-Injury Levels

Economic-injury level equations were determined, with some modifications, according to the procedures outlined by Hammond and Pedigo (1982). The economic-injury level is calculated by dividing the gain threshold by yield loss per insect. The gain threshold (kg/ha) is determined by dividing insect-management costs ($/ha) by soybean market value ($/kg). Information from Section III was used to estimate loss per bean leaf adult. Economic-injury levels were calculated for several combinations of soybean market values and pest-management costs.

Dispersion Analyses

Bean leaf beetle adult dispersion was determined by using data collected from sampling in a soybean field ('Corsoy 79') in 1987 and two soybean fields ('Corsoy 79' & 'Preston') in 1988 located near Ames, IA (Section I). Each field was sampled from soybean stage V4 (Fehr et al. 1971) until harvest maturity with a 38-cm sweep net. Eight sampling units of 40 sweeps (1987) and 50 sweeps (1988) each were taken every 3 to 4 days. Sample counts in 1987 were multiplied by 1.25 to convert to 50-sweep units. Samples in which most of the counts were zero were excluded. A total of 71 samples were collected.

Dispersion of injured pods was calculated from data collected in an artificial infestation study conducted near Ames, IA (Section II). Four replications of five treatments (3 bean leaf beetle densities, a caged check, and an uncaged check) were established. The caged plots, which covered 2m of soybean row, were infested during mid-August at soybean stages R5 to R6. Soybean row spacing was 0.78 m with 25 plants/m. For analysis, each sample consisted of injured-pod counts for four five-plant units, with a five-plant unit taken from each of four plots for each treatment. This provided a wide range of injured-pod means. Therefore, a total of five samples were collected at each sample date. Sample dates included 19 August and 24 September in 1987 and 23 August, 30 August, 9 September, and 10 October in 1988, providing a total of 30 samples.

Iwao's (1968) regression was calculated for bean leaf beetle and injured-pod counts by determining Lloyd's (1967) mean-crowding index ($\overset{*}{m}$) using the following equation:

$$\overset{*}{m} = \bar{x} + (s^2/\bar{x} - 1) \qquad (1)$$

The mean-crowding index then was regressed against the mean number of bean leaf beetles or injured pods per sample ($\bar{x}$) to determine α and β in the equation:

$$\overset{*}{m} = \alpha + \beta\bar{x} \qquad (2)$$

The null hypotheses of H_0: $\alpha = 0$ and H_1: $\beta = 1$ were tested by using the t-test.

Taylor's (1961) power law was calculated by first regressing the log of the variance against the log of the mean sample counts ($\bar{x}$). This provided the least squares estimate for a and b in the equation:

$$\log_{10} s^2 = \log_{10}a + b*\log_{10}\bar{x} \qquad (3)$$

or

$$s^2 = a\bar{x}^b \qquad (4)$$

The null hypothesis of H_0: $b = 1$ was tested for each field and for all data combined.

Sequential-Count Plans

Kuno's (1969) formula was used, according to procedures outlined by Bechinski et al. (1983), to calculate sequential count plans for bean leaf beetle adults and injured pods. The following equation was used:

$$D = (n/T_n^2)\ f(T_n/n) \qquad (5)$$

where D is the desired sampling precision or RV value, n is the number of 50-sweep sampling units (bean leaf beetle) or number of five-plant samples (injured pod counts), T_n is the cumulative bean leaf beetle or injured-pod count, and $f(T_n/n)$ is the sampling variance (s^2) expressed as a function of mean density, where $\bar{x} = T_n/n$ and $s^2 = f(\bar{x}) = f(T_n/n)$. A functional relationship between the variance and the mean can be determined from coefficients calculated in either Iwao's (1968) regression or Taylor's (1961) power law (Bechinski et al. 1983). The dispersion analysis that explained most of the variation between the variance and the mean was chosen, and the corresponding variance/mean relationship was used in Kuno's formula.

RESULTS AND DISCUSSION

Economic-Injury Levels

Economic loss can result from seed-yield loss or from a value discount caused by reduced seed quality (Section III). An economic-injury level formula was determined that considers the seed-yield reduction as the only loss variable. Information from Section III indicated that the bean leaf beetle will cause an average yield reduction of 3.06×10^{-4} kg/adult. A range of pest-management costs ($17.30 to $25.40/ha.) and soybean market values ($0.19 to $0.38/kg) were incorporated into the economic-injury level equation. These calculations indicated that economic-injury levels range from 14.9 to 42.5 bean leaf beetles per m^2 (Table 6).

Information provided in Section III indicates that critical seed damage for incuring an economic discount requires greater insect densities than those thresholds determined from seed-yield losses alone. A minimum of 685 injured pods/m^2 at harvest (assuming a yield of 2600 kg/ha) is necessary to incur an economic penalty. Data from this study also revealed that, at harvest, 3.2 injured pods were observed for each bean leaf beetle sampled. This information indicates that 214 bean leaf beetles/m^2 are needed to cause enough seed damage for an economic penalty. Such a critical value is appreciably larger than the economic-injury levels determined by the yield loss coefficient alone. Consequently, the economic-injury level from yield loss will be exceeded before enough seed damage is incurred to cause a value discount.

Table 6. Economic-injury levels for the bean leaf beetle adult on soybeans during late season expressed as number of adults per m^2 and no. per sweep

Soybean market values, \$/kg (\$/bu)	Pest management costs, \$/ha (\$/ac)			
	17.3(7.00)	19.8(8.00)	22.2(9.00)	24.7(10.00)
0.19(5.00)	29.8(7.2)[a]	34.1(8.2)	38.2(9.2)	42.5(10.3)
0.23(6.00)	24.6(5.9)	28.1(6.8)	31.5(7.6)	35.1(8.5)
0.27(7.00)	20.9(5.1)	24.0(5.8)	26.9(6.5)	29.9(7.2)
0.30(8.00)	18.8(4.6)	21.6(5.2)	24.2(5.9)	26.9(6.5)
0.34(9.00)	16.6(4.0)	19.0(4.6)	21.3(5.2)	23.7(5.7)
0.38(10.00)	14.9(3.6)	17.0(4.1)	19.1(4.6)	21.2(5.1)

[a]Values in parentheses are number of adults per pendulum sweep parallel to soybean row in a field with 0.78-m row spacing and 25 plants/m.

Economic-injury levels were converted from counts per m^2 to numbers per sweep using the procedures of Rudd and Jensen (1977). These values are included in Table 6. Injured-pod counts were used as a population index for bean leaf beetle adult densities. Information from Section II indicates that each adult will feed on an average of 9.8 pods. With this information, economic-injury levels based on injured-pod numbers were calculated for the same range of management costs and market values shown in Table 6, and the results are given in Table 7.

Economic Thresholds

The economic threshold is an integral component of bioeconomics because it accounts for "future injury potential of the population and time delays involved in final suppression" (Pedigo et al. 1989). These authors indicated that a fixed economic threshold of 75 percent of the economic injury level is often recommended for soybean insects. Therefore, for bean leaf beetles, an economic threshold of 0.75 times the economic-injury level was chosen for soybeans that are in developmental stages R5 to R6.

Dispersion Analyses

Both Iwao's regression and Taylor's power law analyses explained a large proportion of the variation in the bean leaf beetle sampling data for individual field and pooled data (Table 8). Iwao's α coefficient was never significantly ($P>0.05$) greater than zero, indicating that the individual was the basic component of dispersion. This agreed with results of Iwao's

Table 7. Economic-injury levels for bean leaf beetle-injured soybean pods during late season expressed as number of injured pods per m^2 and no. per 5 plants

Soybean market values, \$/kg (\$/bu)	Pest management costs, \$/ha (\$/ac) 17.3(7.00)	19.8(8.00)	22.2(9.00)	24.7(10.00)
0.19(5.00)	294(75.4)[a]	336(86.3)	377(96.7)	420(107.6)
0.23(6.00)	243(62.3)	278(71.3)	312(79.9)	347(88.9)
0.27(7.00)	207(53.0)	237(60.7)	265(68.1)	295(75.7)
0.30(8.00)	186(47.7)	213(54.6)	239(61.3)	266(68.2)
0.34(9.00)	164(42.1)	188(48.2)	211(54.1)	235(60.1)
0.38(10.00)	147(37.7)	168(43.1)	189(48.4)	210(53.8)

[a]Values in parentheses are number of pods injured by bean leaf beetle feeding per 5 plants in a field with a 0.78-m row spacing and 25 plants/m.

Table 8. Results of Iwao's regression and Taylor's power law analyses for sweep net samples[a] of bean leaf beetle adults in soybeans, Ames, Iowa, 1986-1988

			Iwao's regression	
Year	n[b]	R^2	α (SE)[c]	β (SE)
1987	19	0.832	0.2963(15.26)	1.508(0.1642)**[d]
1988				
(Field 1)	27	0.999	0.4884(2.081)	1.078(0.006809)**
(Field 2)	25	0.993	3.341(6.995)	1.063(0.01873)**
1987-1988	71	0.973	3.775(10.70)	1.081(0.02161)**

[a]Sample size = 50 sweeps of a 38-cm sweep net along the soybean row.

[b]Number of data points in regression; each data point represents 8 50-sweep sampling units.

[c]Standard error of the mean.

[d]*=P<0.05 & **=P<0.01, t statistic, for H_0:α=0 or H_0:β=1 (Iwao's), or H_0:b=1 (Taylor's).

Taylor's power law	
R^2	b (SE)
0.871	1.786(0.1664)**
0.953	1.468(0.06515)**
0.907	1.478(0.09857)**
0.902	1.553(0.06146)**

regression analyses that were calculated by Boiteau et al. (1979d). Coefficients from both analyses indicated that bean leaf beetle adult populations in Iowa were aggregated, with *ß* (Iwao's) and *b* (Taylor's) significantly ($P<0.01$) greater than one for all individual and combined samples. The *ß* values determined by Boiteau et al. for North Carolina populations ranged from 1.24 to 1.29, indicating a greater degree of aggregation than for most fields and for all data pooled in our study. Taylor's power law calculations by Kogan et al. (1974), however, indicated appreciably less aggregation for Illinois populations than for the Iowa populations, with *b* values of 0.80 to 1.29 for Illinois being produced. The inconsistency in dispersion coefficients among studies may reflect actual behavioral differences among various bean leaf beetle populations; however, differences in sweeping motions and varying sizes of sampling units probably is responsible for this phenomenon.

Iwao's regression and Taylor's power law analyses for injured pod counts were calculated only once with data from both years combined. Neither *ß* (1.028, SE=0.03585, t=0.791, $P>0.05$, n=30) or *b* (1.484, SE=0.2467, t=0.270, $P>0.05$, n=30) were significantly different from one, indicating a random dispersion. Iwao's α was large (8.910) but was not significantly different (SE=7.676, t=1.16, $P>0.05$) from zero. Caution must be used when intrepreting these results. Dispersion coefficients may be appreciably different for injured pod counts collected in the open field.

Sequential-Count Plans

For the bean leaf beetle adult data, R^2 values were greater for Iwao's regression than for Taylor's power law in two of the three fields sampled (Table 8). Iwao's regression also explained a greater proportion of the variation for data pooled for all fields. Therefore, coefficients from Iwao's regression on the pooled data (α=3.775 and β=1.081) were used to calculate the functional relationship between variance and mean for insect samples needed in the sequential count plans ($s^2 = 4.775\bar{x} + 0.081\bar{x}^2$). This function was substituted into equation (1) and critical stop lines for two precision levels calculated (Fig. 8).

Iwao's regression also explained a larger proportion (R^2=0.967) of the variation between variance and mean for the injured pod data than that explained by Taylor's power law (R^2=0.564). The functional relationship between the variance and the mean determined from Iwao's regression coefficients was substituted into equation (1) and stop lines calculated for two precision levels (Fig. 9).

Sequential count plans are used by taking 50-sweep or 5-plant samples in random locations in a field. The cumulative number of bean leaf beetles or injured-pods counted is plotted against the number of samples taken. Sampling is continued until the stop line is exceeded. The density then is calculated by dividing the cumulative number (T_n) by the number of samples (n) collected. The maximum number of samples collected was arbitrarily set at 20. Sampling is discontinued when the maximum number of samples is reached, even though precision will not be at the desired level.

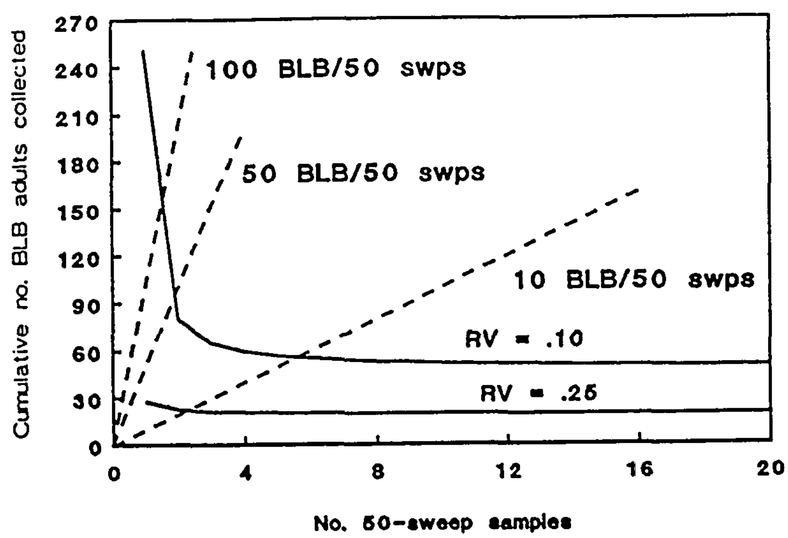


Fig. 8 Sequential count plans for bean leaf beetle adult density estimates with specified levels of precision.

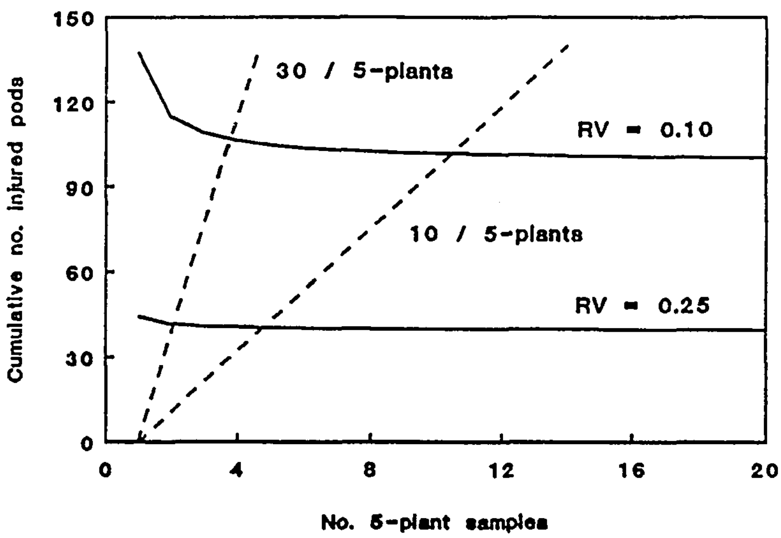


Fig. 9 Sequential count plans for density estimates of pods injured by bean leaf beetle adults with specified levels of precision.

The management guidelines developed from this study are best utilized for scouting during soybean stages R5 to R6 because thresholds were determined from data that were collected in plots artificially infested during these soybean stages. Economic-injury levels for scouting after the start of soybean maturation are probably less than those given in this study because the availability of green pod tissue is reduced. These critical levels probably also would be less for soybeans younger than R5 because the soybeans have greater compensation potential than soybeans in stage R5 or older (Mederski et al. 1973).

SUMMARY AND CONCLUSIONS

Bean leaf beetle adult sampling and late-season artificial infestation studies were conducted from 1986 through 1988 to achieve the following objectives:(1) determine the phenology of the bean leaf beetle adult on soybean and alfalfa in Iowa, (2) ascertain seasonal and diurnal distribution of sex ratio, female reproductive status, and relative proportions of adult color forms, (3) quantify the relationship between bean leaf beetle adult density and injury on soybean stem, leaf, and pod components during late season, (4) assess the effect of bean leaf beetle adult feeding on soybean seed yield and seed quality, (5) formulate economic-injury level equations for late-season injury on soybean by bean leaf beetle adults, (6) determine the dispersion patterns of bean leaf beetle adult and injured pod counts, and (7) develop sequential sampling plans for late season management guidelines.

Data from all three years indicated that two generations of this insect occur in Iowa. Overwintering adults inhabited alfalfa before soybean appearance, colonized soybeans immediately after seedlings emerged, and died by late June. F_1 adults were abundant from late June to mid-or-late August, and F_2 adults from early August to soybean maturation. Females were more abundant than males among overwintering and F_1 adults, but neither sex of F_2 adults was more numerous. The yellow/red adult ratio was greater during the fall than in the spring, indicating greater winter survivorship of red adults. The smallest captures between 0830 h to 2030 h were observed at 0830 h and 1000 h, the period of heavy dew on the soybean canopy. From 1300 h to 1600 h the number of females with developing ovaries declined, whereas the number of females with fully developed eggs increased.

Adults feeding during soybean stages R5 to R7 injured pod surfaces, clipped pods, and fed on leaves and stem surfaces. Each adult injured an average of 9.88 pods in non-drought years and 3.68 pods in the drought year. Significant pod loss differences among treatments were detected only in 1988, with an average of 2.50 pods lost per bean leaf beetle. A significant trend in defoliation with increasing bean leaf beetle feeding days occured in 1986 and 1987, with an average of 6.58 cm^2 leaf tissue removed per adult. Each adult caused an average of 6.90 to 7.14 stem lesions.

At lesser adult densities, the bean leaf beetle caused fewer pod lesions per pod, less injured-pod area per pod, and greater injured-pod area per pod lesion than at greater adult numbers. Also, on the average, approximately one third of the injured pods in 1986 and one fourth of the injured pods in 1987/1988 were located in the top four soybean nodes.

Each bean leaf beetle adult per m^2 resulted in a 3.06 kg/ha yield loss. Over 600 injured pods/m^2 were necessary for sufficient seed damage to incur an economic discount. Official damaged seed weight per injured pod seemingly was dependent on late-season rainfall. The number of seeds with greater than 50 percent of their surface tissue darkened was more consistently correlated with the number of injured pods than the number of seeds with less than 50 percent darkened tissue or the number of seeds that were lightly discolored or shriveled and without darkened tissue.

Economic-injury level equations were determined for late-season bean leaf beetle pod injury. Tables were provided that contain economic-injury levels based on adult and injured-pod counts for several combinations of pest-management costs and crop-market values. Economic-injury levels based on seed-yield loss were exceeded before economic penalties were incurred from damaged seed in surface-injured pods. Economic thresholds were set at 0.75 times the economic-injury level. Both Iwao's regression and Taylor's power law analyses indicated that the adults are significantly aggregated, but injured pods are randomly distributed. Sequential count plans were developed for bean leaf beetle-adult and injured-pod sampling.

As with other pests of soybean, the economic injury level equation for late-season bean leaf beetle feeding probably is appreciably effected by soybean phenology. Feeding studies during soybean stages other than R5 to R6 would provide excellent supplemental information to the data collected in this study.

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